The Role Gender Plays in Spatial Navigation and Recall Ability

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The Role Gender Plays in Spatial Navigation and Recall Ability

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Abstract:

Memory recall in order to complete certain tasks such as spatial navigation, and, in turn prospective planning, is largely necessary for day-to-day activities which require travel. Due to various factors, females and males, may react to the stress of spatial navigation differently. In fact, it is said that females tend to perform worse on spatial navigation tasks but tend to react better to stressful situations, in general. Hence, one hypothesis is that females will be more likely to revert back to habitual methods to reach their destination, rather than to think on their feet in order to create a novel shortcut that may help them reach their destination more efficiently and effectively. Alternatively, the evidence for better performance in some tasks in females under stress might lead to the opposite prediction. My report below details a pilot study in a preliminary sample of ten participants, to be continued post-graduation, that goes on to study spatial navigation gender differences by using a virtual spatial navigation and memory task. I test in this pilot sample whether there is evidence males and females differentially prefer habitual routes or shortcut routes when travelling to a destination.

Introduction:

Memory recall is an important function that allows humans, regardless of sex, to act efficiently and effectively in various circumstances, whether it's finding the best route to the grocery store; or, taking a test. Unfortunately, in many real-world settings, the ability to function to the best of one's ability may be negatively influenced by stress. Specifically, elevated cortisol levels are said to negatively influence an individual's episodic memory retrieval mechanism in terms of prospective planning. Spatial navigation is a ubiquitous real-world activity in which prior experience within a context informs prospection and planning of future actions (Brown, Gagnon, Wagner, 2020).

Given the information above, it is established that stress negatively affects episodic memory retrieval and in turn prospective planning as well as spatial navigation regardless of sex. However, sex does play a large role in cortisol level stability or fluctuation, and gender may contribute to the act of navigating itself being a stressful experience. In other words, the extent to which stress manifests and causes an effect may be different depending on sex. In this study, Python code presents different virtual environments for participants to learn and navigate. Additionally, Matlab code will be used to probe memory recall of objects scattered throughout the previously mentioned environments. Analyzing route patterns collected during these spatial cognition tasks will allow for the study of how sex impacts the effects of stress on memory in terms of habitual vs. shortcut route preference.

Certain epigenetic factors include basal cortisol levels (Adreano, Cahill, 2006), sensitivity and density of glucocorticoid receptors (Espin, Gomez-Amor, Hidalgo, 2015), amygdala activity (Aufdenkampe, Burke, Hoffman, etc., 2014), and menstrual cycle conditions (Gaab, Hellhammer, Kirschbaum, etc. 1999). Certain environmental factors include social integration levels (Chin, Cohen, Murphy, 2018), social exclusion levels (Helpman, Penso, Zagoory-Sharon, etc., 2017), usage of oral contraceptives (Abercrombie, Gaffey, Hoks, etc., 2014), and diurnal cycle conditions (Smyth, Ockenfels, Gorin, etc., 1997).

Overall, this experiment studies the effects of sex on cortisol levels and the extent of its effect when an individual is tasked with completing a spatial navigation and memory task in males (control condition) and females. It is hypothesized that due to the various factors cited above and higher general wayfinding anxiety (Lawton, Kallai, 2002), females are generally predicted to perform comparatively worse on spatial navigation tasks; however, this is not a foregone conclusion and is worth continued study because females are generally known to perform better under stressful conditions in some tasks. Men and women of the same age (sans any external factors) generally have similar baseline cortisol levels. Hence, I set out to study the role sex plays in spatial route recall ability and spatial navigation route preference in the face of stress that the spatial navigation and memory tasks cause. Due to research challenges in the pandemic, my report details a preliminary dataset (N = 10) that we will continue to build upon and test my predictions about stress more fully after graduation.

Literature Review:

Previously it has been found that when persons of the same sex are presented with a spatial navigation task, those in stressful conditions with higher cortisol levels perform worse or tend to rely on a habitual pathway rather than take flexible shortcuts; additionally, their memory recall is negatively affected. However, there is very little data in humans on the variability of the impact of stressors amongst different ages and genders, and to what extent “normal” tasks like the act of navigating are themselves stressful. Hence, the broad aim of this research is to study the effects sex has on cortisol levels and the extent of cortisol elevation during spatial navigation and memory performance.

Based on previous research various biological factors may play a role in cortisol level differences in people of different sex. These include pre-existing baseline differences in cortisol levels, the female estrus cycle, and disintegration of glucocorticoid receptors. In terms of baseline cortisol levels, it has been shown that there is no overall mean difference between baseline cortisol concentrations of male and female participants, and that both genders show significant increases in cortisol to cold-pressor stress (a cardiovascular test performed by immersing the hand into an ice water container). Interestingly, however, it has been found that these same levels of cortisol response in males and females may affect memory consolidation differently (Andreano, Cahill, 2006). Hence, varying neural reactivity to cortisol could help explain different memory recall abilities in men and women. In fact, there is evidence that although men and women have similar baseline cortisol levels, men who showed robust cortisol response to a stressor exhibited enhanced long-term recognition memory, while male participants who demonstrated a blunted cortisol response to a stressor exhibited impaired long-term recall and recognition memory (Aufdenkampe, Burke, Hoffman, etc., 2014). Hence, these findings suggest that the effects of pre-retrieval stress on long-term memory are sex specific and men are more affected by stress than women in terms of declarative memory retrieval. Critically, they suggested in the literature that this may relate to differential amygdala activity coupled with hormonal differences and males having a larger amygdala while females have a stronger amygdala-hippocampus neural network. In other words, different neural reactivity to cortisol in men and women may be due to different anatomical morphology and amygdala connectivity.

There is also evidence that females generally perform better under stressful conditions when given a memory recall task, and this has been linked to potential beneficial effects of female sex hormones (Buchanan, Tranel, 2008). Because these hormones fluctuate over the female menstrual cycle, gender differences in cognition may vary. For example, women who were in the luteal phase (phase in the menstrual cycle when the egg is released) produced more cortisol than men in response to a 0.25 Adrenocorticotropic hormone (ACTH) injection; however, women who were in the follicular phase (phase in the menstrual cycle when the egg is developing) produced less cortisol than men in response to ACTH. On the other hand, women who were in the luteal phase produced the same amount of cortisol as men in response to the Trier Social Stress Test (TSST); however, women in the follicular phase produced less cortisol than men in response to the TSST (Gaab, Hellhammer, Kirschbaum, etc. 1999). In relation, the luteal phase is associated with reduced glucocorticoid sensitivity (Schoofs, Wolf, 2009). Collectively the data above indicate that when glucocorticoids are secreted in response to stress, they can have a different impact on cognition in women depending on the menstrual phase.

Such gender and menstrual cycle-related differences in cortisol responses are important for memory because generally, glucocorticoid receptor activity is thought to enhance memory consolidation, but reduce the ability to retrieve information (Wolf, 2006). Activity at these receptors also tends to interfere with short-term memory. In relation, elevated cortisol levels, as a result of endocrine psychiatric disorders or age-associated changes in the hypothalamus pituitary adrenal (HPA) system, generally have a negative influence on memory.

In addition to the above biological factors differentiating sex in stress responses, other external factors may also play a role in any small or large cortisol level difference in people of different sex. These include the use of oral contraceptives, diurnal cycle (day-and-night biological cycle), and social integration levels. One study found that females who reportedly took birth control were not significantly different from naturally cycling females on any physiological or behavioral measure, nor did stress significantly interact with birth control (Aufdenkampe, Burke, Hoffman, etc., 2014). However, comparably, it was found that women who were on any oral contraceptive were less receptive to stress. They had the lowest cortisol level rise under stressful conditions (0.25mg ACTH injection and TSST) compared to women in the luteal phase, men, and women in the follicular phase based off a salivary test (Gaab, Kirschbaum, Kudielka, etc., 1999). In addition, hormonal birth control (HBC) use is associated with a greater cortisol increase: when given a controlled dose of hydrocortisone, cortisol levels may increase more dramatically in women taking HBC versus women not on HBC or men (Abercrombie, Gaffey, Hoks, etc., 2014). Hence, there are many contradictory results of the extent that oral contraceptives effect cortisol levels. Based on diurnal cycles, it has been found that baseline cortisol levels decline throughout the day regardless of sex. This may add to further fluctuation; hence, it is best to run participants at around the same time of day (1 PM – 4 PM) (Brown, Gagnon, Wagner, n.d.). Lastly factors such as social integration levels may interact with biological influences on the stress response. Increased social integration has been associated with steeper diurnal cortisol slopes regardless of sex (Chin, Cohen, Murphy, 2018). Following social exclusion, all participants experienced mood worsening followed by mood improvement. Men were found to be less affected than women. This was seen through a clear decline in female cortisol levels and a non-significant rise and decline in men cortisol levels (Feldman, Gilboa, Helpman, etc., 2017). Hence, prior social involvement may be another factor influencing cortisol levels; therefore, adding variability in the data.

In conclusion, it is apparent that various biological and external factors play into the fluctuation and variability of cortisol levels across a large group of individuals. Hence, these factors must be considered when studying the effects of sex on cortisol levels and the extent of its effect on cognitive tasks such as spatial navigation and memory recall which depend on neural systems that are impacted by cortisol. Surprisingly little data in humans has directly addressed how sex interacts on such cognitive demands – or account for such external factors. I propose to do so here, lending new insight into how males and females may differ in their ability to remember and navigate under stress.

Critical for the present study, the act of navigating itself can be stressful – especially when the route to be followed is uncertain. There is some evidence that this is subject to a gender effect, with females experiencing greater "spatial anxiety" than males (Lawton, 1996). This can impact navigation strategy and mediates spatial cognition on more basic levels such as performance on the mental rotation test (Lawton, Kallai, 2002). In males, psychological stress during the task presented below is disruptive to their performance (Brown, Gagnon, Wagner, 2020), but the above data suggest the detrimental effect of stress on females in this task is less easy to predict, especially if it is endogenous (due to the task itself, rather than an external stressor.

Materials and Methods:

In order to examine the effects of sex and accompanying cortisol levels on spatial navigation route preference, participants underwent several spatial navigation and memory tasks developed by our lab with intermittent tests of saliva cortisol hormone levels. Python code presented participants with spatial navigation and memory problems that depend on hippocampal memory retrieval in six different virtual environments (described below). Additionally, MatLab code was used to probe memory recall of landmark objects scattered throughout the previously mentioned environments. Through analyzing male and female route performance and preference, inferences regarding the effects of stress can be concluded.

Participants were split into two groups: male (control) and female (experimental). All of the participants underwent a two-day task using the virtual environments. The navigation task was recently published in (Brown, Gagnon, Wagner, 2020). In brief: Day 1 consisted of preliminary questionnaires and learning specific routes through each environment and their associated landmark objects. In order to learn the routes, participants underwent several guided trials of each off the environments with four intermittent memory tests. The questionnaires included a health screening, supplemental demographic information, and a survey regarding key environmental and biological factors (e.g., Did you feel increased levels of stress? Did you sleep your normal amount last night?) that are known to affect cortisol levels which can be accounted for in analyses. Day 2 first tested probe how well participants remembered the familiar routes in each of the six towns. This was critical because it helped in interpreting their behavioral performance or strategy on subsequent Day 2 tasks. In these subsequent tasks ("Probe trials"), participants were placed at a pseudorandom location along their familiar route and asked to navigate to familiar landmark object elsewhere in the environment as efficiently as possible using whatever strategy they like. The design allowed quantification of how their strategy on these probe trials changes as a function of sex and induced stress (due to the tasks itself). (i.e., do they use memory to plan and take a shortcut, or do they fall back on habitual routes? How precise is their spatial memory?). Note that in cases where the environment is more complex, or a participant's memory is less certain even for the familiar route, the probe trial may be more stressful. Moreover, taking a novel route is inherently less certain – participants don't know their shortcut will work out. Therefore, wayfinding a shortcut may be more stressful – especially in women (Lawton, 1996). Saliva samples will be collected on Day 1 and 2 to establish cortisol baselines and stress effects. My analysis will compare route preferences between males and females in terms of habitual versus shortcut pathways. Using graphical and statistical analyses, I will relate these hormone differences to continuous memory performance and categorical navigational strategy measures, while factoring in the additional external factors collected. In doing so, my study will provide truly novel data comparing stress reactivity across varying sex and establishing its link to spatial navigation and memory.

Figures:

Figure 1a) The following figure depicts an example of a habitual (familiar) route, in one environment, that the participants were required to learn in day 1 and follow in day 2. The orange path illustrates the intended habitual route and the blue path illustrates the route the participant took.

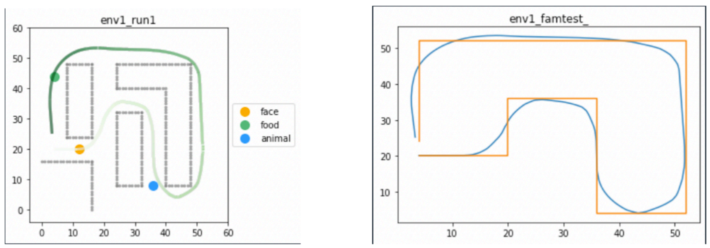


Figure 1b) The following figure depict the two probe trials (one in orange and one in blue; left plot) in which participants were asked to navigate to a specific object in day 2. The right two plots illustrate these two routes the participant took (now both in blue) relative to a portion of the habitual route (now in orange) in order to reach the object. Note that this participant did not follow a habit, in this example – rather, although they retread the familiar route on both trials, they did so flexibly by backtracking along the familiar route to their current goal instead of taking the long way around (top and bottom right plots). In both cases, this backtrack is only slightly worse than the most optimal shortcut they could take.

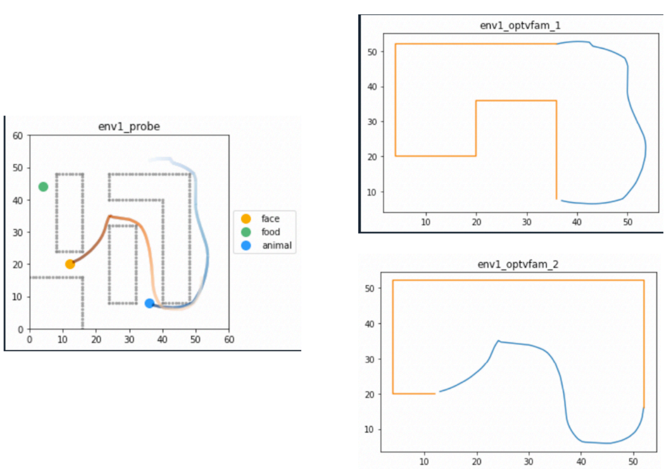


Figure 2) The following figure depicts the average Fréchet distance for Males and Females across environments between the intended habitual (familiar) route that the subjects are told to follow and the subject route.

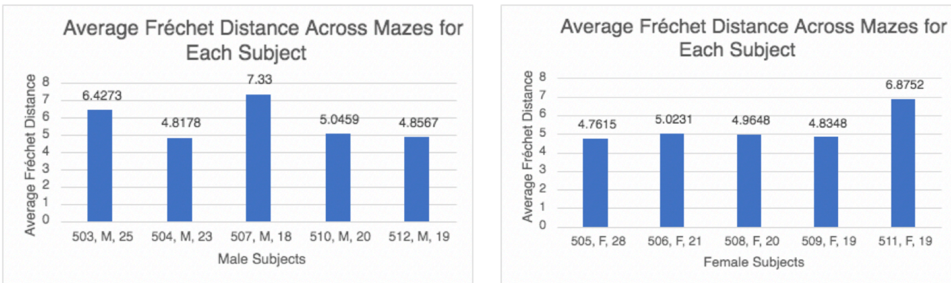


Figure 3) The following figure depicts the average Fréchet distance for Males and Females across environments between the intended shortcut (optimal) route and the subject route for Probes 1 and 2.

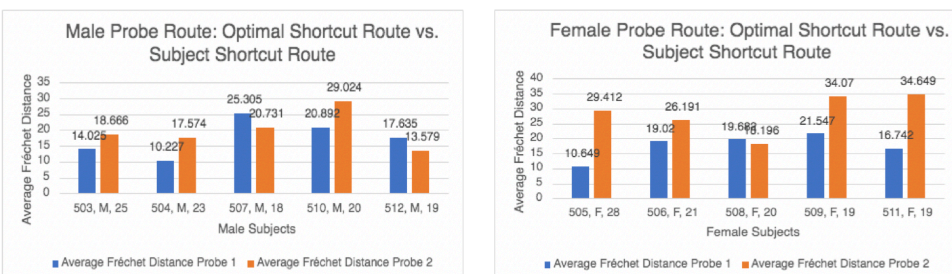


Figure 4) The following figure depicts the average Fréchet distance for Males and Females across environments between the intended habitual (familiar) route and the subject route for Probes 1 and 2.

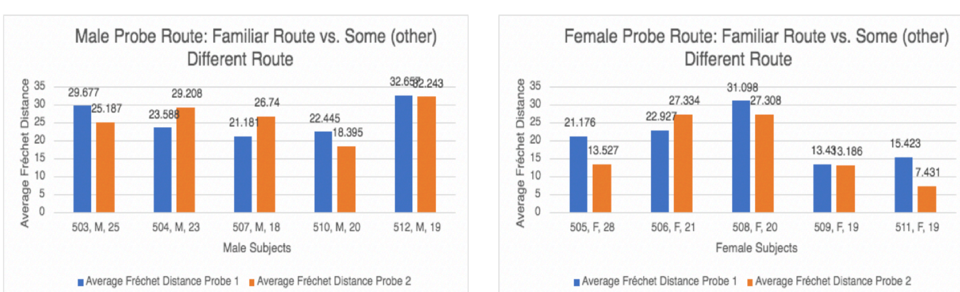


Figure 5) The following figure re-visualizes the same results from Figures 3 and 4. It now depicts the average Fréchet distance for Males and Females across environments of the intended habitual (familiar) route and the shortcut (optimal) route side by side, separately for Probes 1 and 2 (instead of Probe 1 and Probe 2 bars side by side for just shortcut or just familiar route Fréchet distances).

Figure 6) The following figure depicts the average Fréchet distance difference for Males and Females across mazes between the intended habitual (familiar) route and the shortcut (optimal) route for Probes 1 and 2, indicating if the participant preferred one type of route over the other.

Figure 7) The following figure depicts the average shortcut (optimal) route Fréchet distance for Males and Females for each environment across Probes 1 and 2.

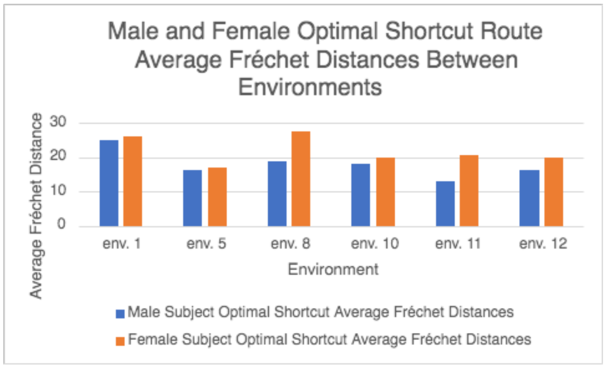
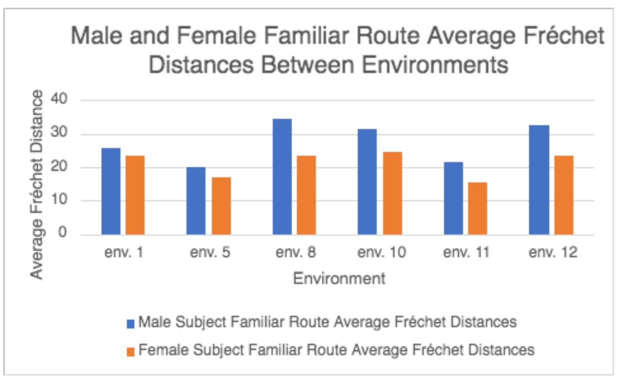


Figure 8) The following figure depicts the average habitual (familiar) route Fréchet distance for Males and Females for each environment across Probes 1 and 2.



Results and Discussion:

In general, the results of this study are based off of average Fréchet distances between males and females in terms of various route performance analysis. A Fréchet distance is a measure of similarity between curves (in this case between the habitual route and the subject's taken route, and/or the novel optimal shortcut route and the subject's taken route) that considers the location and ordering 2D coordinates along the curves. Hence, a small Fréchet distance indicates that the participant was closer to following the reference route (familiar or shortcut). On the other hand, a large Fréchet distance indicates that the participant was farther from following the reference route. Examples of a small and large Fréchet distance are depicted in

Figure 1a and *Figure 1b*, respectively. In other words, if the blue line (the subject route) is close to the orange line (the indicted route), then the Fréchet distance is small; and, vice-versa.

Figure 2 indicates whether the subjects remembered the (habitual) routes for each environment that they were taught in Day 1 during the beginning of Day 2. A Small Fréchet distance indicates that the subject followed the habitual route; while, a large Fréchet distance indicates that the subject likely became confused or lost. Please note that any Fréchet distance larger than 17 caused that specific environment for the subject to be thrown out across the board, in all subsequent analyses of the probe trials, so as to prevent the data from the probe trials being uninterpretable. For example, subject 503 had a Fréchet distance of 34.749 for environment 8 on the habitual route trial. This indicates that subject 503, likely got extremely lost in the environment when they were supposed to simply follow the familiar route from the day before. If the subject was unable to follow the habitual route for an environment, it is likely that they did not learn it well enough to consciously choose between taking a habitual route or shortcut route moving forward, defeating the purpose of the experiment – and indeed any "shortcut-like" behavior could be misinterpreted since it actually likely means they were just wandering or lost. Hence, this environment was thrown out for subject 503. Overall, based on *Figure 2*, both the males and females remembered the habitual routes for each environment similarly, as the Fréchet distance values are about the same, and very well (note that Fréchets of ~4-5 relative to the familiar route are easily achieved simply by not treading the center of each hallway perfectly and are thus in the realm of noise, whereas my cutoff of 17 indicates a participant deviated by, e.g., a city block and thus took a different stretch of road). However, on average, males had 1.4 environments dropped while females had 1 environment dropped. This may indicate that females were better at recalling the habitual route learned on Day 1 during Day 2 trials. A larger sample than could be obtained during this past year with the pandemic will be needed to verify whether this "route forgetting" frequency is different between genders.

But how did the genders compare on the probe trials? This is where the extent data suggest males and females likely differ in strategy as well as navigation-related stress (and associated performance differences). *Figures 3 and 4* indicate the average Fréchet distances between the subject's taken route and the optimal shortcut route as well as the subject's taken route and the habitual route, respectively, for Probes 1 and 2. The relative Fréchet distances for the optimal shortcut and familiar routes therefore indicate the relative strategic bias of the individual – for environments that they actually remembered (see cutoff in previous section), do males' routes more closely resemble optimal shortcuts or retracing of the familiar paths? How does this compare with females? Based on *Figure 3*, it seems as if both males and females tended to have a higher average Fréchet distance for Probe 2 compared to that of Probe 1. This indicates that for Probe 2, both males and females strayed farther from the shortcut route on the second repetition of the probe task. This may be due to the fact that it was generally harder to navigate to Probe 2 because Probe 2 was always structured in a way where the shortcut was oriented in the backward direction relative to the familiar path; or, "against the grain". This makes it more tempting, and perhaps even easier, for a subject to orient themselves to a novel route in the environment and proceed accordingly on Probe 1 than Probe 2.

Because of this, I hypothesized I might see larger differences in performance between males and females on Probe 2. On the other hand, in *Figure 4,* both males and females seem to have about the same average Fréchet distances for Probe 1 and Probe 2. Numerically, in *Figure 3*, more females had higher average Fréchet distances, particularly for Probe 2, indicating my hypothesis may be supported. In *Figure 4*, numerically more males had higher average Fréchet distances for both Probe 1 and Probe 2. This may indicate that females prefer habitual routes, especially in the more difficult Probe 2 scenarios, while males prefer shortcut routes or at least exploring new paths (which would be indicated by a poor shortcut Fréchet but also a high Fréchet distance from their well-learned familiar route, as seen in Figure 4).

I tested these potential differences formally. *Figure 5* depicts the "bias" – the relative Fréchet distance for each person between optimal shortcut and familiar routes. The bias shows that the average Fréchet distance for the habitual route is often much larger than that of the shortcut route Fréchet for the males; and, vice-versa for the females. Hence, females are more likely to take the habitual route than the optimal route, as compared to males. Even in my small pilot sample, this is corroborated by a marginal p-value of 0.1087 (t-stat. = -2.0581, d.f. = 4) for males (Fréchet distance from the optimal shortcut smaller than that for the familiar route), as opposed to a p-value of 0.4222 (t-stat. = -0.89322, d.f. = 4) for females in Probe 1 (indicating females were somewhat split between familiar and optimal shortcut choices, such that there was no difference on average in their Fréchet distances for the two route types.

Interestingly, in Probe 2 the data in my sample were more variable and so neither gender approached a significant bias towards one route type or the other (a p-value of 0.2539 (t-stat = -1.3313, d.f. = 4) for males and a p-value of 0.1913 (t-stat. = 1.5707, d.f. = 4) for females in Probe 2. However, although these values are not significant, they are trending in the correct direction. Hence the pilot data are consistent with my earlier predictions and it will be interesting to follow these tendencies as our sample size reaches an appropriate level.

Were the "familiar vs shortcut biases" different between genders? Figure 6 depicts the average Fréchet distance difference between the habitual and shortcut routes across environments for each participant (i.e., extracting the "bias" from Figure 5). Hence, a positive average Fréchet distance indicates that the subject followed more of a habitual route than a shortcut route. The statistics associated with this figure continue to corroborate the evidence that females prefer to take habitual routes rather than shortcut routes as well as my prediction regarding the difficulty of the two types of Probe trials. This claim is supported by the marginally significant difference between males and females in Probe 2, specifically. While the p-value for Probe 1 is 0.3855 (t-stat. = -0.91832, d.f. = 7.934), indicating males and females had a similar bias, the p-value for Probe 2 is 0.07829 (t-stat. = -2.0511, d.f. = 7.1991), indicating the familiar-route-oriented Fréchet distance bias in females was approaching significantly lower than the bias scores in males even in my small pilot sample.

How did environment identity factor in? Perhaps gender differences only manifest in certain environments (some were larger and more complex, and could skew differences between genders in a similar way to Probe 1 vs. Probe 2) *Figures 7 and 8* depict the average shortcut and habitual Fréchet distance across Males and Females for each environment across Probes 1 and 2. Overall, the Fréchet distances for each environment averaged out to be similar for both males and females. However, in terms of the individual environments, some gave the appearance that they helped drive the evidence of gender effects I saw above (particularly Environment 8 and 11). The average Fréchet distance difference between males and females for Environment 8 did not differ (p-value = 0.2595, t-stat. = -1.2181, d.f. = 7.6248), but the average Fréchet distance difference between males and females for Environment 11 was significantly different (p-value = 0.01232, t-stat. = -3.7298, d.f. = 5.274), indicating females took significantly less efficient routes specifically in that environment. On the other hand, in terms of the Fréchet distance of the routes taken vs. the habitual routes, the average Fréchet distance difference between males and females for environment 8 again didn't differ (p-value = 0.2555, t-stat. = 1.2306, d.f = 7.5425) (suggesting the underlying variability across subjects was high), but environment 12 approached a trend (p-value = 0.1136, t-stat. = 1.8338, d.f. = 6.3556). Overall, it seems as if in environment 11, specifically, females were significantly less efficient compare to their male counterparts, suggesting this may be a particularly important environment to keep an eye on as the sample continues to grow.

Conclusion and Future Directions:

Overall, my preliminary data indicates that females prefer to use habitual routes rather than novel shortcut routes when navigating through certain environments (under stress of navigation itself). This data is important because it allows understanding of route performance, and, in turn, prospective planning methods between males and females. This can prove useful in day-to-day activities such as routing to the grocery store.

Given that this is a pilot study with preliminary data, there are still large amounts of data to be collected. Unfortunately, due to delays because of the pandemic, participant recruitment could not be completed, and the cortisol data needed to address whether there were indeed gender differences in how stressful navigation on our task are out for analysis at this time and could not be included. Moving forward, the lab intends to build off the current data in order to not only continue to compare route performance between males and females but also between young and older adults in order to determine if cognitive deterioration, in some aspects, affects route performance, and, in turn, prospective planning. The lab also intends to analyze subject cortisol saliva samples when the results arrive, and to compare the results between genders as well as collect new data examining gender and age differences in the stress response in the presence of a manual stressor stimulation (threat of electrical stimulation). This latter comparison will enable us to conclude the effects of deliberately induced external stressors on route performance, relative to internally-generate stress responses to the act of navigating itself (as I focused in on my idea for this thesis) order to conclude the effects of deliberately induced stress on route performance, and, in turn, how difference types of stress affect prospective planning and strategies.

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